ANNOTATED BIBLIOGRAPHY OF IMPACTS OF RIPRAP HABITATS ON FISH POPULATIONS

AUTHORS	TITLE	SUMMARY
PACIFIC NORTHWEST		
1. Knudson and Dilly 1987 NOTES: 1. Lower Deschutes data is most similar to Skagit conditions. Riprap only on a larger stream. Decker Ck. secondmost similar. 2. No coho were found at the Lower Deschutes test section.	Effects of riprap bank reinforcement on juvenile salmonids in four Western Washington streams.	- Looked at summer and fall populations. - Coho and trout YOY suffered somewhat in newly riprapped sections of larger streams. Stlhd/cutts increased. - Negative short-term affects of construction appeared to increase with severity of habitat alteration, to decrease with increased in stream size, and to decrease with increasing fish size. -Previous research shows: lost production under certain conditions in streams having discharges of less than 10 ft3/s (Chapman and Knudson 1980). Large decreases in salmonid production after channelization (but not riprapping) on Big Beef Ck a larger stream. (Cederholm and Koski, 1977). - Other studies show potential to increase production through additions of habitat complexity, but little done to show effects of removing habitat complexity. - Results show fish increases over time in all larger stream construction sites except for 0+ trout. Increases were smaller than increases seen in control sites, indicating more preference for control sections.
2. Chapman and Knudsen 1980 NOTES: Channelization impacts winter habitat most. Some test sites had more biomass in summer than controls. Determined to be because of less vegetation and more light.	Channelization and livestock impacts on salmonid habitat and biomass in western Washington	- Worked in streams of less than .3m/sec velocity. -Characterized impact by exposure of raw soil, in water placement of riprap, time since disturbance, and general appearance. -Significance was determined at .10 - During summer sampling, coho (smallest) least affected and cutthroat (largest) most affected. -Noted no possible predator/prey correlation for cutthroat and coho. - 25% more fish in test in summer; 95% less fish in winter. - Neither test nor control reaches held many coho salmon during winter as biomass was only 2% as in summer. - Inferred that light is an important limiting factor for salmonid biomass in summer in many streams. - Removal if the canopy and streamside vegetation over substantial reaches can cause low salmonid biomasses.
3. Li and Shreck 1984 NOTES: Study focused on all species of fish including cyprinids, catastomids, centrarchids, salmonids, and cottids.	Comparison of habitats near spur dikes, continuous revetments, and natural banks for larval, juvenile and adult fishes of the Willamette River.	- The numbers of species of fishes and densities of larval and juvenile fishes at spur dike (groins) are intermediate between natural banks and continuous revetments. Spur dikes accumulate woody debris better. - Two factors were consistent: juvenile fishes avoided velocities greater than 11 cm/sec and were found at depths no greater than 30 cm. - fish composition between natural and rip rap banks differed. Briefly, high densities of a smaller number of species were found in revetted habitats. Mostly those that fed on bottom dwelling inverts and green algae/diatoms and small fishes able to use the interstices as cover (Hjort et al., 1983).

Therefore cooler waters were actually a detriment. - Determined groins provided better habitat than continuous revetment. Not enough information on salmonids to determine their preferences although other references infer preferences to roughened habitats.		-Observed larval fishes in the interstices of the riprap banks near shore but were unable to sample. - Largescale sucker juveniles were supported best by natural banks, spur dikes and lastly continuous revetments. - Juvenile sculpins did not use rip rap to any great degree. A few were caught. - bass, bluegill, catfish, and crappie were not caught in rip rapped sections.
4. Cederholm and Koski 1977 NOTES: 1. Report describes widespread damage to system from bulldozing a new channel. Little discussion on stream bank problems.	Effects of stream channelization on the salmonid habitat and populations of lower Big Beef Ck.	- Big Beef Ck. channelized by bulldozer to reduce flooding - Increase in sediment contribution, scour. Decrease in habitat characteristics. - Coho recovered faster than steelhead in the four years. - Chum salmon redds declined but shifted upstream to compensate for channelized sections. - Bank cover returned to 1/2 prechannelized cover in 4 years. Alders at 2m. - Evidence that coho may avoid dense cover in summer and prefer open glides (Ruggles, 66 and Chapman and Bjornn 1969). Steelhead may be prefer dense shade (Boussu 54 and Chanman and Bjornn 1969). - recommend use of riprap as alternative to channelization.
5. Cedarholm, JC 1972 NOTES: stated reason for channelizing was to improve salmon and trout rearing and spawning habitat and for flood control. Channel was bulldozed and cleared. Pools and cover changes were measured. Traditional chum spawning areas within the project area were found to move upstream and outside the channelization.	The short term physical and biological effects of stream channelization at Big Beef Ck. Kitsap County, Washington.	-Peters and Alvord (1964) studied the effect of man-made stream channel alterations on game fish (trout) production in 13 Montana streams. They found that altered channels produced only 1/5 the number of game fish and 1/7 the weight of game fish as natural channels. Gebhards (1970) reports on studies of 45 different Idaho streams that had undergone stream alterations. It was found that undisturbed stream channels produced from 1.5 to 112 times more pounds of game fish than disturbed channels. On the average, undisturbed sections contained 8 times greater poundage of game fish. Baldes (1971) found that channelization of Big Spring Ck. Montana has resulted in complete destruction of trout stream habitat. After channelization, the pools riffles, bank vegetation inverts., and other essentials were gone. Stroud (1971) reported that various construction activities affecting rivers and streams, particularly direct modification of natural meanders through straightening and deepening causes substantial losses of productivity compared to the original natural stream configurations. - The chum salmon may recognize the lack of hiding cover in this area of the stream. The resulting reaction was to move to a more suitable area upstream. - Accelerated streambank erosion and streambed degradation within the channelized area. - preferred habitat of both coho and steelhead is in

		association with pools. pool with permanent hiding cover have been found to result in the greatest overwintering salmonid populations (Bjornn 1971, Hunt 1969). Their abundance in pools presumable represent an integration of all the other factors besides space that regulate their health and numbers, such as food production in the riffle areas. Pool densities were low compared to conditions before channelization. - two years following stream channelization, the number of juvenile coho per m2 increased to about 1 1/2 times the density before channelization. Densities were measured in pools only. - Steelhead recovery is slow partially because of reduced streambank cover. -Bossou 1954 found he could reduce number and weight of trout by removing streambank cover. Newman noted rainbow trout swam from place to place in a pool in Shagehen ck. in relation to overhead cover. Saunders &Smith 1961 found that alterations that increased hiding places increased the % survival of brook trout fingerlings. -Hunt 1969 concluded that increases in overwintering survival of brook trout were due to physical improvement in space refuge factors (cover, depth, pool area). - Bjornn 1971 found a reduction in emigration of rainbow and chinook when there was substantial amounts of cover provided by large rubble.
6. Orsborn, JF 1990 NOTES: Interstitial spaces used by rainbow, cutthroat and chinook.	Pilot study of the physical conditions of fisheries environments in river basins on the Olympic Peninsula	- Commonly, newly emerged fry move to shallow margins (Hartman 1965, Chapman and Bjornn 1969, Everest and Chapman 1972, Krueger 1981, Cunjal and Power 1986). - Migration to deeper and faster water occurs as most species grow. - All species move to cover areas and objects when water temperatures decrease in the fall and winter (Bjornn 1971, Bustard and Narver 1975, Cambell and Neuner, 1985, Taylor 1988. - Overwintering habitat is the limiting factor in many drainages: (a) interstitial spaces are used by juvenile rainbow, cutthroat and chinook. Side channels are used by coho.
7. Wisssmar and Beer 1994 NOTES: LWD contributes to habitat complexity and potential carrying capacity.	Distribution of fish and stream habitats and influences of watershed conditions, Beckler River, Washington	-During the 1980's concern about declining coho and chinook fish stocks led to cooperative efforts in initiating stream channel, bank stabilization and habitat improvement project in the Beckler River basin. Monitoring of populations has been too infrequent to determine the success of these project. - LWD recruitment occurs as channels shift and streambanks erode during periods of high discharge. - The presence of LWD increases the surface area and roughness which contributes to habitat complexity and potential carrying capacity. - Degradation of stream habitats by channel erosion and

		removal of LWD is evident in the greatly reduced habitat diversity and potential capacities to support fish. -The stream network needs to connect habitats required for 1) various fish life histories, 2) refugia from disturbances, 3) source areas that provide population for colonizing disturbed and restored habitats (Sedell et al. 1990, USDA Forest Service 1994).
8. Lister, D.B. et al 1995	Rock size affects juvenile salmonid use of streambank riprap.	-Assessment of habitat alteration in two southern BC streams. Thompson River wetted channel is 100-200m wide and carriers a mean annual discharge of 775m/s -Thompson River, large riprap supported higher chinook salmon and steelhead trout densities than small riprap and cobble-boulder banks during summer and winter. -Densities were greater along large riprap than small riprap banks, but wild coho exhibited no preference. -Suitable banks for juvenile salmonids were relatively steep, contained large rock and were constructed in a way that maximized roughness. -Study sites were used for rearing and overwintering primarily by juvenile chinook salmon 0+ and rainbow steelhead trout. - Coldwater River supported a population of wild coho. - It was assumed that salmonid juveniles at the study sites were rearing, not actively migrating. - Assumed the visual method provided valid estimates of relative bank material size. -Noted in previous winter studies (Edmundson et al, 1968) juvenile salmonids were hiding within the substrate during the day. - Juvenile chinook, coho and steelhead parr were higher at boulder placement sites than reference sites without boulders. -Drifting insects are usually the primary food source for salmonids (Chapman and Bjornn 1969; Bachman, 1984) Drift at a given point appear to be positively related to water velocity (Everest and Chapman, 1972; Wankowski and Thorpe, 1979). Everest and Chapman (1972)observed that juvenile chinook salmon and steelhead trout occupied stations that allowed them to hold position in low or virtually zero velocity, usually near the stream bottom but adjacent to high velocity flow. -Large riprap usually supported higher juvenile salmonid densities than banks composed of either natural cobble - boulder material or small riprap. - Fish distribution was highly clumped. 72% caught at 17% of site. -Additions of large boulders have been shown to increase stream habitat capability for juvenile coho salmon and steelhead trout (Ward and Slaney 1993) - Interstices within the riprap blanket also provide hiding places for fish (White and Brynildson, 1967). The preference of Thompson River chinook and steelhead for

		large riprap in winter reflects their tendency to seek cover within a boulder or rubble substrate for overwintering (Hartman, 1965; Edmundson et al 1968; Bustard and Narver 1975). -Riprap embankments intended to provide habitat for juvenile salmonids should be constructed of coarser material than would be specified on the basis of commonly used design criteria. Also the practice of providing a hydraulically efficient surface is contrary to habitat requirements.
9. Hayman R.A et al 1996 NOTES: Backwater and natural banks more productive than riprap. Setback levees in lower river could be very productive. Does not include lower Skagit habitats.	FY 1995 Skagit River Chinook Restoration Research	- Upper Skagit River habitat production study. - Compared backwaters, natural banks, hydromodified banks (RipRap), and bar habitat. -0+ chinook production (fish/m2) 1.78 backwater, .97 natural, .348 riprap, .44 bar habitat. - Yearling chinook not rearing in any of the sampled areas. - Three types of life history. 1) emergent fry migrating to ocean, 2) emergent fry rearing in estuary before ocean 3) fingerling migrants (90 day) that emerge and reside in freshwater before ocean. - Chinook utilization of hydromodified banks averaged 4 times less than natural banks.
10. Peters, R.J et al 1998 USFWS, North Pacific Coast Ecoregion Western Washington Office Aquatic Resources Division, Lacey, Washington.	Seasonal Fish Densities Near River Banks Stabilized with Various Stabilization Methods, First Year Report for the Flood Technical Assistance Project.	-Evaluated seasonal salmonid densities at five different types of bank stabilization projects (riprap, riprap with LWD, rock deflectors, rock deflectors with LWD (combination), and LWD) relative to natural control areas near the stabilized site. -LWD stabilized sites were the only stabilized sites to consistently have greater salmonid densities than their associated control areas. -Juvenile chinook and total juvenile salmonids densities during the spring were significantly less at riprap stabilized sites than natural control areas. -Coho fry densities during the spring were significantly less at combination stabilized sites than natural control areas. -Salmonid fry, total juvenile salmonids,and total fish densities during the winter were significantly greater at LWD stabilized sites than natural control areas. -1+ trout densites during the spring were greater at combination stabilized projects than natural control areas, but were less at rock deflector stabilized sites. -1+ trout densities during the summer were significantly less at riprap stabilized sites than natural control areas. -2+ trout densities during the spring were significantly less at deflectors than at natural control areas. -0-age trout densities during the spring were greater at rock deflector sites than at natural control areas. -LWD incorporated into riprap and rock deflectors did not improve rearing conditions for juvenile salmonids. The authors believe that this was the result of poorly designed

		LWD. The LWD formed only sparse cover for salmonids, since single logs or trimmed rootwads were used. The performance of LWD mitigation in riprap and rock deflector projects may have been improved if LWD forming complex cover, which provided juvenile salmonids refuge from predators had been incorporated.
11. Missildine et al. 2001.	Habitat complexity, salmonid use, and predation of salmonids at the bioengineered revetment at the Maplewood Golf Course on the Cedar River Washington	-Examined the influence of modifying a riprap bank stabilization project into a rock deflector, LWD, and bioengineered (combination) bank stabilzation project on habitat complexity and fish densities from January to mid June. -Habitat complexity, in the form of secondary habitats and cover increased at the new combination project compared to the old riprap project -Mean water velcocities at the new combination project were more favorable for juvenile salmonid rearing. -Relative densities of salminds parr and cottids were consistently greater at the new combination revetment than at a naturally stable bank that served as a control -Juvenile chinook salmon and total salmind relative densities were generally less at the new revetment compared to the control area during January through March, but were greater from April through June. -Relative densities of chinook salmon, salminid parr, total salmonids, and cottids were greater at the new combination project than the old riprap project. -Predation on salmonids was relatively low at the combination project and the control area.
12. Beamer, Eric A. and Richard A. Henderson. 1998 Skagit System Cooperative Report prepared for U.S. Army Corps of Engineers, Seattle District, Environmental Resources Section. La Conner, Washington.	Juvenile Salmonid Use of Natural and Hydromodified Stream Bank Habitat in the Mainstem Skagit River, Northwest Washington.	- Compared juvenile salmonid use at natural and hydromodified banks types in the mainstem Skagit River - Natural banks had a greater occurrence of wood versus hydromodified banks - Wood cover was found to increase in time after hydromodification - Juvenile chinook and coho had significantly higher abundances in areas with greater wood cover. - Juvenile rainbow showed some preference for riprap (large size rock) - Fish abundance was greater in rootwad cover versus single logs for all species except sub-yearling chum - Sub-yearling chum prefer aquatic plants and cobble - The findings suggest that the use of natural cover types along with bank protection may mitigate some site (but not reach) level impacts of hydromodification
CALIFORNIA		
10. Shields, F.D 1991. NOTES: Outlines detrimental affects of vegetation. Reduction of channel conveyance, impairment of revetment visibility for inspection,	Woody vegetation and riprap stability along the Sacramento River Mile 84.5 -119.	- Since revetment vegetation occurs along riparian corridors, its habitat value per unit area is greater than similar vegetation in blocks away from waterways. - Aerial photography showed that about 11 percent of the revetted segments supported woody vegetation types 2 or 3 prior to the flood, but only 9 percent after the flood. - relative to aerial photos, state inspection records under-reported revetment vegetation by about 80 percent,

hindrance of flood fighting activities, and adverse effects on revetment durability from local scour by growth and uprooting of trees. Piping through levees by roots (Gray et al, 1991)		indicating only 3 and 2 percent of the revetted bank line was vegetated before and after the 1986 flood respectively. - Review of 84-99 files revealed five instances of revetment damage attributed to the 1986 flood in the study reach. None of the five sites supported woody vegetation before or after the flood. - Damage rate for vegetated segments was roughly twice as high as for unvegetated segments, this was evidently due to the fact that vegetated revetments were generally older. In fact, when revetments of similar age, material, and location were compared, vegetated revetments were less likely to be damaged.
11. USFWS 1992 NOTES: Study on Sacramento River Rock groins replaced some habitat values. Full replacement not seen but vegetative recovery not incorporated into data.	Juvenile salmon study Butte Basin reach: Sacramento River Bank Protection Project.	- study was to determine the relative abundance of juvenile chinook salmon in relation to various modifications of rock revetment. - 3 year monitoring results -looked at natural banks, rock fish groins, and standard revetment. - rock revetment alone had the lowest average habitat value and lowest value 2 of 3 years. -Rock groins had the greatest incremental benefits when comparing habitat improvement against cost. -Present bank stabilization practices and riprapping destroys most if not all unique values of shaded riverine aquatic cover. - Irregularly-shaped riverbanks are straightened and covered with uniform smooth layer of quarry rock. -Results of study do indicate that the experimental mitigation measures were able to recover some habitat values lost to revetments. None appeared to provide full replacement of habitat value based on the salmon utilization measurements. Avoidance mitigation by using set-back levees and other approaches should be pursued.
12. USFWS 1988 NOTES: Statistical effort to determine density dependent effects. -Sacramento River	Study of the effects of riprap on Chinook salmon in the Sacramento River, California	- More juvenile chinook salmon can be captured in cutbanks than in riprap in the Sacramento River. The significance of these observations depends in whether or not density dependent mortality is important for young salmon that depend on the limited amounts of food and space available in the river. - consequently, efforts to evaluate alternative to standard riprap such as different slope configurations and use of larger rocks should be continued. -- Along tern effect perhaps centuries, could result from cessation of bank erosion by eliminating most of spawning gravel recruitment. - If loss of habitat is the only direct result of riprap (quantity change but not quality change) and there is surplus rearing habitat, then their will be no effect of riprap on the production of salmon. - Where rearing habitat is limited, survival of juveniles salmon may decline because fish grow faster or avoid

		predators more effectively in the unaltered habitat. -Satisfactory approaches are not available to assess separately the effect of a loss in quality of habitat and of a loss in quantity of habitat. Approaches are not available because knowledge of the movements and distribution of young salmon is sketchy and capture of a large proportion of the fish in a reach of stream generally is not practical. -Recommend the effects of riprap be reduced by pursuing the reduction or elimination of harmful effects of bank stabilization habitat. Results should be applicable to other systems. - Expect that the acceptability of riprap to juvenile salmon increases with size of the rock although it may also increase for predator fishes.
13. State of California Dept of Fish and Game. 1983 NOTES: Sacramento River Major diet components not significantly different between test and control areas.	Sacramento River and tributaries bank protection and erosion control investigation. Evaluation of impacts to fisheries.	- Found 3 insect families comprised the majority of chinook diet. Chironomid, mayflies, and aphids. No statistical differences in the abundance of these insects was found between cutbank and riprap areas. -Average of only 1.3 the number of chinook in riprap vs control areas. Related to increase in thickness of zone of turbulent flow of large rock. -Higher species diversity in riprap. Also large rock related. - Steelhead trout not addressed but found at project area. Appears that no significant differences apparent between riprap and natural. -Majority of salmon fry move during darkness (Lister and Genoe 1970; Chapman 1966). Reimers (1977) reported that most downstream migration and emergence from gravel occurred at night with daytime movement less than 5%. - Newness of riprap when compared to older sites may have affected preference. No evidence given to support this but increase of terrestrial vegetation over time was not mentioned. - General observations indicate that low velocity areas with considerable cover tend to have higher daytime salmon densities than the type of habitat typical of cutbanks. Riprap affects probably do not extend all the way to mid-river. -Approximate 6% reduction in abundance of adult spawners was estimated from the project. Near worse case estimate. - alternative methods of bank stabilization may reduce the losses of fish by sloping banks to provide shallow water habitat at greater flow ranges.
14. ECOS. Inc. 1991 NOTES:	Biological data report regarding Sacramento River Bank Protection Project impacts on winter-run chinook salmon. Second	- 22-26 % reduction of river edge riparian habitat since 1972. Most attributed to bank stabilization(DeHaven, 1989) -Primary effects of riparian loss on chinook salmon production are through changes in water temperature, reduced instream cover objects, and reduced habitat diversity.

Riprap size/type and its potential affects on salmonid use. 2-3 % of historical woody riparian vegetation remains along the Sacramento River. Currently confined to 30 feet either side. - Potential adverse impacts resulting from second phase bank protection on previously described habitat components are interrelated; difficult to quantify, and individual incremental impacts possibly are minor.	and third phases.	-Most significant intermediate impacts to fishery resources occurs from bank protection projects which typically entail removal of nearshore riparian vegetation, grading of the bank slope, and placement of rock revetment over the graded slope. -Principal causes for low utilization of revetted areas by chinook juveniles are believed to be unsuitable velocity characteristics along riprap substrate, and reduction of large instream cover objects (Schaffter et al, 1983; Michney and Diebel 1986; Michney, 1989a). Drift densities of invertebrate prey species may not be significantly different (Schaffter et al, 1983). - Data from other regions suggest impacts greatest during fry stage due to their narrower tolerance of depth and velocity extremes (Li et al, 1984; Knudsen and Dilley 1987). -Streamflows encountered by winter run chinook fry less likely to cause downstream displacement into riprapped areas than for other run types which emerge during winter or spring. - Riprap probably affects smolts most during those periods when fish are stationary and feeding (typically daylight hours). - Juvenile chinook are frequently found associated with instream cover (Chapman and Bjornn, 1969; Lister and Genoe 1970; Michny and Diebel, 1986). Instream cover is important to rearing juvenile chinook salmon as shelter from predators and from severe environmental conditions and for development of efficient feeding stations. Explanation for there presence at sites without instream cover not given. -Low hanging riparian vegetation , undercut banks and emerged woody debris are important to rearing juvenile salmonids as protection from avian and terrestrial predators and as sources of shade (Reiser and Bjornn, 1979). -Little is known concerning the important of shade to juvenile chinook salmon although some evidence suggests that it may be significant during periods of elevated water temperatures (DeHaven, 1989). -Construction related increases in water turbidity were local and temporary. Juvenile salmon will avoid turbid water (Bisson and Bilby 1982) as will adult salmon (Whitman et al, 1982). Decreased production of fish food organisms from turbidity are considered less than significant. - Water velocity associated with large angular rock may negate positive characteristics and partly explain the low utilization of riprap by juvenile chinook salmon. - replacement of woody debris or natural substrate cover with quarry rock results in a reduction of habitat quality. This result was evident in the middle reaches of the Sacramento River (Schaffter et al, 1983; Michny and Hampton 1984; Michny and Deibel 1986) although data

		from the lower river and delta was inconclusive (DeHaven 1989; Strait and Michny 1989). - Michney 1989a found higher numbers of juvenile chinook salmon associated with cutbank rock revetment sites, at which both gravel and fish groins had been added, than were found at nearby natural areas. - Juvenile chinook abundance was observed to be higher at rock revetted areas with fish groins than at standard rock areas although the extent of the mitigative value of groins has not been quantified.
TROUT HABITAT		
15. Hunter, CJ 1995 NOTES: -Most studies on smaller streams. -Montana streams. -Baken Park was a Corps project	Better trout habitat- A guide to stream restoration and management.	- Common mistake is to stabilize the eroding banks on the outside of meander bends. This eroding process is natural and creates prime habitat. -If the riparian vegetation is in poor condition, the erosion can be greatly accelerated, leading to the loss of land and to dished out banks that do not provide cover. Often the response to this situation is to provide structural bank protection in the form of riprap. However this locks a stream into a preferred course and limits ability to create trout habitat. - Stream bank revetment is generally rock. Rock can take the form of a continuous blanket or a series of jetties, both can provide trout cover and stabilization. Trees and brush can also provide cover and stabilization but have shorter life spans than well placed rock. -To meet the obligation to control bank erosion, ODFW uses bank sloping, rock jetties, and in some cases rock riprap. -Boulders have been placed along the margin of the stream where overhanging grasses provide cover. These boulders breakup a long riffle and provide rearing habitat for juvenile trout. Riprap both up and down stream of these boulders are used to protect the boulders. - Data collected indicated that the habitat created by boulders placed along banks in riffles contains juvenile chinook and steelhead. Adults use boulder berms for resting. - Baken Park, large riprap provided breaks in the flow that creates cover and lies for trout. large rock was placed to provide feeding stations and cover for trout. The project benefited brown trout and caused a decline in the sucker population.
16. Moyle, P 1976 NOTES: Channelization is both riprap and channel straightening. Smaller fish using	Some effects of channelization on the fishes and invertebrates of Rush Creek, Modoc County, California	-Channelized sections contained fewer and smaller trout as well as a lower biomass than the unchannelized sections. Overall total fish biomass in the channelized sections was less than one third of that in the unchannelized sections. - Negative effects on fish and invert. populations recognized, but poorly documented (Schneberger and Funk 1971, Barton et al, 1972, Wilkenson 1973).

channelized section. Seen this before, could be hierarchy related.		-Average size of rainbow trout, brown trout, and Modoc sucker were less in channelized sections. Pit sculpins and brown trout were more abundant in the channelized sections. - 80% of biomass in channelized section was rainbow and brown trout. Fish including pit sculpins were larger in unchannelized sections. - Studies in Montana show that channelization reduces the average size and number of trout per surface area of stream. (Whiteney and Bailey 1959, Elser 1968). - Lost carrying capacity was caused by loss of pools, overhanging bushes, large boulder and other cover. Only riffle dwelling fish were able to use the scant cover and turbulent water maintained by the channelized sections.
17. Bianchi and Marcoux 1975	The physical and biological effects of physical alteration on Montana trout streams and their political implications. IN: Symposium on stream channel modification.	- There were approximately 3 times as many brown trout in a natural section as compared to a bulldozed section and two times as many as compared to a riprapped section. - Estimated number per 1000 feet natural= 132.3($\pm$20) riprapped = 58.1 ($\pm$17.6)
18. Simpson, P.W. 1982. NOTES: Good sections on biological impacts. Use for background purposes.	Manual of stream channelization impacts on fish and wildlife.	-Channelization effects tend to be more pronounced for aquatic organisms, and upstream effects are probably greater than downstream effects.
19. Martin, VJ 1971	The place of channel improvement in watershed develop-ment In: Stream Channelization: a symposium.	-Documented evidence of irreparable damages to fish and wildlife is needed at this early stage so that local people can and will recognize mitigation and enhancement practices for fish and wildlife.
MISSISSIPPI RIVER		
20. Dardeau, E.A 1995 NOTES: Mississippi River study	Using rip rap to create or improve riverine habitat.	Case studies illustrate the habitat value of riprap, which is particularly pronounced in alluvial rive systems dominated by soft substrates. - Riprap provides hard substrate for invertebrates, which is especially important in alluvial river systems where this material is scarce or absent (Mathis et al. 1982) - Non keyed placement can provide direct habitat benefits to fishes because such placement of riprap approximates natural situations in which velocity and substrate size are positively associated.

21. Shields and Hoover 1991 NOTES: Stabilization projects can provide habitat and refugia for some fish species. Study done in Mississippi with limited application to PNW. Describes the importance of providing heterogeneity in habitat characteristics at bank stabilization projects.	Effects of channel restabilization on habitat diversity, twenty mile creek, Mississippi	-Grade control structures (GCS) (weirs with stone protected stilling basins) and various types of streambank protection were constructed along the channel in the early 1980's to restore stability. - GCS also promote biological recovery in unstable, channelized streams by providing coarse, stable substrate. -Three GCS and assorted streambank protection measures (concrete jacks, stone revetments and combinations of structure, grasses, and woody species, primarily Salix spp) were installed. GCS consisted of sheet pile or stone weirs with crests above the stream bed and approach channels and stilling basins lined with stone riprap and graded stone riprap. - The frequency of eroding banks was greatly reduced due to the presence of riprap revetments. - Diversity was variable among all stations but was higher in Twenty mile Creek, especially at GCS, presumable due to higher levels of physical diversity there. Stream channelization and destabilization reduce physical aquatic habitat heterogeneity. Although the relationship is complex, stream fish communities respond positively to increasing levels of habitat heterogeneity. -GCS and bank protection structures facilitate habitat recovery in two ways. By promoting overall channel stability, and serve as major habitat features. -Stabilization structures can provide refugia for fishes experiencing reductions in available habitat. Channel modification projects would be less detrimental to aquatic ecosystems if they were designed and constructed with two-stage cross-sections that included low-flow channels. - Species diversity and richness of fish communities in channelized streams are positively associated with structures which increase depth, decrease velocity and increase physical heterogeneity at low flow.
MIDWEST		
22. Funk, JL and Ruhr, CE 1971	Stream Channelization in the midwest. In: Stream Channelization: a symposium	- A ditch does not provide suitable habitat. - All of the states reported that stream fish habitat had been destroyed and degraded by channelization.
23. Hansen, DR 1971	Stream channelization effects on fishes and bottom fauna in the Little Sioux River Iowa. In: Stream Channelization: a symposium.	- Numbers of fish species were greater in the unchannelized section. - Bayless and Smith 1967 reported a 90% reduction in the number per acre of fish over 6 inches long in 23 channelized streams. In the 40 years following channelization there was no significant return to normal stream populations. - Removal of streambank cover was an important factor contributing to such conditions as higher water temperature and higher suspended sediment loads from channel

		erosion. -Results seemed to indicate that channelized sections were not favorable to stable populations of larger game fish.
24. Heneger and Harmon 1971	A review of references to channelization and it's environmental impact. In: Stream Channelization: a symposium	-Pounds of fish per acre in the channelized portion of the Blackwater River in Missouri were 131, in the slightly channelized reaches 449 (mostly carp) and the unchannelized section 565 (primarily channel catfish (Belusz 1970). - Twenty three channelized streams and 36 natural streams compared in the Lower Piedmont and Coastal Plain of North Carolina were significantly different. Channelization reduced the number of game fish (>6") per acre by 90%, the weight by 85% and the standing crop by 80%. There was only limited recovery after 40 years. - The Little Sioux River in Iowa had water temperatures with greater daily fluctuations during the summer in the channelized section. Consistently higher turbidities were found in the channelized portion. Colonization of macroinverts. on artificial substrates suggested lack of suitable attachment areas in the channelized portion. Numbers of fish were fewer in the channelized section (Hansen and Munsey, 1971). - Flint Creek (Montana) a trout stream had a 350 foot section dredged, cleared, and straightened. This section had been previously inventoried for fish populations for several years. In 1955, a year before the dredging, a total of 20 pounds of fish were taken in this section. Dredging began in 1956, and in 1957, after the channel "improvements", 1.5 pounds of fish were found in the same section. (Stroud, 1971). -Seven times as many catchable-size trout and over 60 times as many whitefish were collected in natural stream sections as in those which had been subjected to various types of alterations (Idaho). By weight , the differential was 14 to 1.
FOREIGN SOURCES		
25. Jungwirth M. et al. 1993 NOTES: Recovery after 3 years is briefly described during a reconditioning of a channelized section of stream by adding groins and bedfalls.	Effects of river bed restructuring on fish and benthos of a fifth order stream, Melk, Austria.	- Benthic drift decreased significantly in the restructured river section, suggesting unfavorable conditions for many benthic invertebrates in the straightened section. Terrestrial invertebrates however, occasionally entering the water body , showed a ten fold increase in drift in the channelized reaches. - Number of fish species increased from 10 to 19 and fish density and biomass as well as annual production of 0+ fish increases three-fold. Modeled productions weren't realized suggesting more time is needed to establish a balanced community.
26. Jurajda, P 1994 NOTES: Study done on tributary to the	Effect of channelization and regulation of fish recruitment in a	- In the absence of areas with lentic backwaters or side-arms with aquatic vegetation in the channelized river, the fish could only use the stabilized banks of stony rip-rap or rare shallow slope gravel shorelines.

Danube. Limited applicability. Characteristics of riprap similar to PNW Large angular rock, often silted.	flood plain river.	- Shoreline important as nursery for all 0+ fishes (Floyd et al, 1984, Mills and Mann 1985). -Spawning and nursery sites, now limited to the main channel shoreline. -Balon (1974) who said that fish were more influenced by changes in reproduction conditions than by changes in food sources.
27. Hortle and Lake 1983	Fish of channelized and unchannelized sections of the Bunyip River, Victoria.	- Australian report. - Short term effects include a reduction in the numbers and biomass of the resident fish populations of the stream (Beland 1953, Moyle 1976, Marzolf 1978, Chapman and Knudson 1980). - Long term effects depend on whether populations can recover by adapting to the new conditions. - Area of snags present appears to be an important correlate of fish abundance. - Duvel et all (1976) found that channelization reduced trout populations and concluded that lack of suitable physical habitat was the major cause. - Trout were both more abundant and reached a larger size at the unchannelized sites than at the channelized sites.

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